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Effects of Continuous

Military Operations on Physical Fitness

Capacity and Physical Performance

by

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Abstract

The purposes of this study were to determine the effects of a continuous field artillery scenario on physical fitness capacity and performance and to estimate the physical intensity of the scenario by continuous heart rate monitoring. Twenty-four artillerymen comprising three, 8-man guncrews participated in an 8-day, combat-simulated operation. Body composition and measures of fitness (isokinetic strength of the arms and legs, isometric handgrip strength, dynamic lifting, and upper body anaerobic power) were determined before and immediately following the scenario. Physical performance was assessed by daily ratings from senior noncommissioned officers experienced in artillery operations. The intensity of physical activity and amount of sleep were estimated from continuously recorded heart rate using electrocardiographic tape recorders worn by the soldiers. No changes occurred in body weight or upper body anaerobic power from pre to post- scenario. However, measures of muscular strength and lifting capacity increased by 12-18% post-scenario. Physical performance scores were significantly higher on days 1 and 8 compared to the other days but no differences were seen from days 2 through 7. The mean ± SD for daily sleep was 5.3 ± 1.3 hrs. The soldiers averaged 22 min and 2.9 min per day, respectively, at heart rates equal to or greater than 50% and 75% of their maximal heart rates. The results suggest that soldiers who are allowed 5 hrs sleep per day and who are required to perform at relatively moderate levels of physical intensity show no decrements in physical fitness capacity or evidence of physical fatigue for up to 8 days of continuous operations.

Key Words: Continuous operations, physical capacity, physical performance, Medilog, performance (human), exercise, military operations

Introduction

The effects of sustained physical activity and sleep loss on human performance in the industrial setting have been studied in both laboratory and field environments over the past few years (Alluisi and Morgan 1982). More recently efforts have been directed to assessing such effects in military sustained operations by employing prolonged, combat-simulated scenarios (Haslam 1981, 1982, 1985; Murphy, Knapik and Vogel 1984; Myles and Romet 1986; Legg and Patton 1987). Such studies are dictated by the notion that future conflicts will be characterized by high intensity operations lasting for periods exceeding an individual's capability to maintain efficient performance. Results of such studies also apply to a variety of crisis situations requiring sustained physical activity and sleep deprivation (e.g. search and rescue missions, medical and civil emergencies).

Most studies on sustained military operations have been concerned with the effects of sleep loss on vigilance tasks and cognitive performance (e.g. Haslam 1981, 1982, 1985; Angus and Heslegrave 1985) and have dealt only briefly with physical performance (Haslam 1981). The results of such studies have shown cognitive and vigilance tasks to deteriorate rapidly over time but demonstrate little if any material effect on aerobic power and submaximal endurance exercise (Haslam 1981). However, recent continuous operations studies involving both sleep loss and high levels of physical exertion reported significant decrements in various measures of muscular strength and anaerobic capacity (Murphy et al. 1984; Legg and Patton 1987).

The present study further investigated the impact of continuous operations on physical fitness capacity and physical task performance of field artillery soldiers operating for 8 days under combat-simulated conditions. In addition, the physical intensity of the scenario was assessed by the continuous monitoring of participants' heart rates.

Methods

Subjects were 24 qualified field artillery soldiers assigned to three howitzer guncrews (8 men per gun) designated as Alpha, Bravo, and Charlie. All subjects were fully briefed regarding the purpose and nature of the study and their informed consent was obtained prior to participation. The three guncrews were part of a large field artillery exercise which took place at a US Army training area and lasted 8 days. This was a continuous, combat-simulated scenario for artillery guncrews and involved frequent moves (5-7 per day), resupply missions each day, emplacement of camouflage twice daily, frequent fire missions (20 to 65 per day) requiring the handling and loading of shells weighing 45 kg, and other tasks normally associated with artillery operations. These activities were the same for all guncrews but varied in time of day according to individual guncrew scenario requirements. All subjects were provided 3 hot meals per day and maintained adequate food and fluid intake throughout the 8 days. An average of 3713 Kcal was consumed each day (Rose and Carlson, 1986). The average temperature during the scenario was 21°C with a range of 14-29°C. The relative humidity averaged 79%.

Four days before the scenario during a 4 hr period in the morning and at approximately the same time of day immediately post-scenario, subjects underwent a series of physiological tests to identify changes in physical fitness capacities pre to post-scenario. The tests were performed in the same order at both times and consisted of body composition by skinfold measurement, muscular strength measures, lifting capacity and upper body anaerobic power. Percent body fat and fat free mass were estimated from the sum of four skinfolds (biceps, triceps, subscapular, and suprailiac) according to Durnin and Womersley (1974). The maximal isokinetic strength of both the elbow flexors and knee extensors at angular velocities of 30°/s and 180°/s was determined using the Cybex isokinetic dynamometer (Ramos and Knapik 1980). Right isometric handgrip strength was measured with a handgrip dynamometer developed in this laboratory. Maximal lift capacity to a height of 152 cm was determined by an incremental dynamic lift device where weights are raised on a vertical scale in incremental steps until a maximum lift is achieved (McDaniel, Skandis and Madole, 1983). Upper body anaerobic power was determined by the Wingate test (Bar-Or 1978) where the subject maximally cranked a cycle ergometer for 30s at a resistance of 0.05 kg/kg body weight. A Monark cycle ergometer was modified with a lever arm for instantaneous application of resistance (Frederick, Langevin, Miletti, Sacco, Murphy and Patton 1983). The number of pedal revolutions and the resistance were used to calculate power output in watts (W). Power outputs were expressed as peak power, the mean power output of the highest 5s period (usually the first 5s); mean power, the average power output over the 30s period; and power decrease, the difference between peak power and the lowest 5s power output divided by time and expressed as a percentage.

Subjects' age, height, weight and physiological responses to maximal exercise (aerobic capacity) were determined prior to the pre-scenario testing session. The latter were measured by an interrupted, uphill treadmill running protocol according to the method of Taylor, Buskirk and Henschel (1955). The mean ± SD values were as follows: age 22.2±3.6 yrs, height 176.5±5.5 cm, weight 76.1±11.1 kg, maximal oxygen uptake 52.1±5.5 ml/kg/min, and maximal heart rate 191±7 beats/min.

The physical task performance of each subject was evaluated twice during each day of the scenario by senior noncommissioned officer personnel knowledgeable in all phases of artillery operations. Two evaluators who rotated on a 12-hour basis (0700 to 1900 hrs and 1900 to 0700 hrs) were assigned to each guncrew. A rating scale from 1 to 10 (with 10 being the highest score) was used to rate the soldier's ability to perform all physically demanding tasks. The rating reflected such attributes as how energetically or actively tasks were performed, the ability to handle the physical demands of the job, signs of fatigue versus "freshness", and the forcefulness or aggressiveness displayed in the performance of tasks. A single performance score was calculated for each subject each day of the scenario.

The intensity of the physical activity of the scenario was estimated using portable, electrocardiographic (ECG) tape recorders (Medilog, Oxford Instruments) worn by the crewmen. A three lead, V_5 ECG configuration was used to optimize the R-wave amplitude from which heart rate was determined. Cassette tapes were changed and the integrity of the recorder and ECG preparation evaluated between 0700-0800 each day. The daily heart rate for each subject was recorded on one, 24-hr cassette tape. This was replayed for computer analysis through an Oxford replay unit interfaced to a Hewlett-Packard 85A desk top computer (Mello, Jones, Vogel and Patton 1987).

A baseline heart rate was determined for each subject each morning during the exchange of tapes. This heart rate was taken with the subject in the standing position and served as the basis for determining the time crewmembers spent sleeping and at heart rates above 50% and 75% of maximal heart rate. The criterion used to estimate sleep was a heart rate 10 beats/min below the baseline value and which persisted for 20 min or more. Heart rates at 50% and 75% of maximal heart rate were calculated by multiplying the difference between the maximal and baseline heart rates by 0.50 and 0.75 and then adding these values to the baseline heart rate.

A one-way analysis of variance for repeated measures was used to determine significant differences in physical fitness capacities resulting from the 8-day scenario.

Results

There were no statistically significant pre-scenario differences in physical characteristics or exercise capacities among the three guncrews. The data, therefore, were combined and the results from both the pre- and post-scenario testing periods are presented in Table 1. There was no change in body weight when subjects were combined or when the guncrews were evaluated separately. On the average a significant decrease in percent body fat (4%) and increase in lean body mass (1.3%) was found post-scenario compared to pre-scenario. These changes were due to an 11% decrease in the percent body fat of Charlie guncrew as members of the other two guns showed no significant changes.

Power outputs expressed relative to body weight during upper body anaerobic exercise showed no changes from pre to post-scenario. All indices of muscular strength, however, increased significantly ranging from 7% for isometric handgrip strength to 12-18% for measures of isokinetic strength. In addition, maximal lifting capacity increased significantly (14%) from pre-to post-scenario. Similar increases were seen for all guncrews.

The mean physical performance ratings each day of the scenario are presented in Table 2. The ratings were significantly higher on the first and last days of the scenario compared to the other days. No day-to-day differences in performance were seen from days 2 through 7.

The mean time spent per day sleeping and at various levels of physical activity as determined from continuous heart rate monitoring is presented in Table 3. Incomplete heart rate data were obtained for many subjects over the 8-day period due either to a failure of the electrode preparation to remain intact or to the subject removing the electrodes because of skin irritation or interference with movement. Thus the number of subjects with complete data varied considerably across days (Table 3). The mean daily amount of sleep obtained for all subjects over the 8-days was 5.3 hrs with individual averages ranging from 3.5 to 6.8 hrs. Approximately 90% of this sleep came during the nocturnal period. No significant differences occurred across days in the time spent asleep for any of the guncrews. In addition to sleep, subjects spent a mean of 5.5 hrs per day at heart rates equal to or below the baseline level. The baseline heart rates were not significantly different among guncrews and averaged (±SD) 77±2, 76±3, and 81±3 for Alpha, Bravo, and Charlie, respectively.

Table 3 also depicts the mean time subjects spent each day at physical intensities equal to or above 50% and 75% of their maximal exercise heart rates. The mean (±SD) values were 134±5 and 163±6 beats per minute, respectively. The time spent at heart rates 50% and 75% of maximal averaged

22 min and 2.9 min per day, respectively. At both heart rate intensities, values for Alpha and Bravo were significantly lower than for Charlie ($p<.05$).

The mean hourly heart rates for each guncrew during Day 4 of the scenario are shown in Figure 1 as a representative example of the intensity of the scenario. Similar heart rate patterns were found for the other days where mean values generally ranged from 80 to 100 beats per minute during the active period (0700 to approximately 2400 hrs.). A general pattern was established which was similar for each day of the scenario. Gun movements occurred from approximately 0800 to 1600 with ammunition resupply taking place later in the evening (1900--2200 hr). The highest mean heart rates were found for each guncrew during the resupply period. The scenario called for a relative lull in operations between 2300 and 0700 hrs where fewer fire missions took place than during daylight hours, and there were no gun movements.

Discussion

The major finding in this study was the lack of any evidence of physical fatigue as assessed by measures of physical fitness capacity and ratings of physical performance resulting from participation in an 8-day continuous field artillery operation. The observations relative to changes in muscle strength and endurance contrast with those reported by Murphy et al. (1984) who found reductions in upper body mean power from the Wingate test and in isokinetic strength of the elbow flexors for infantry soldiers immediately after a 5-day combat-simulated scenario. More recently, Legg and Patton (1987) also reported decrements in upper body mean power as well as isometric handgrip strength following an 8-day field artillery trial. In both of these studies there was an unusually high degree of upper body exercise throughout the scenario in the form of either backpack load carriage (Murphy et al. 1984) or manual handling of artillery shells (Legg and Patton 1987).

The absence of any decrease in measures of physical capacity and ratings of physical task performance may reflect differences either in the intensity of the physical task demands or in the amount of dedicated sleep the soldiers obtained compared to the other scenarios. Both factors would significantly impact upon the physical performance of soldiers in a continuous operations environment. In the study by Legg and Patton (1987) soldiers handled a significantly greater number of artillery shells per day, lost a mean of 1.9% in body weight over the 8-days, and averaged less sleep (approximately 3 hr) per day compared to the 5.3 hrs of sleep for subjects in our study. These differences suggest a much greater energy expenditure and thus a more physically demanding scenario which could account for the differences in muscular strength and anaerobic power seen during post-testing between these two studies. Furthermore, based upon continuous heart rate measurement, in the 5-day infantry scenario (Mello et al. 1987) soldiers spent nearly 70% more time per day (37 min) at heart rates equal to or greater than 50% of their maximal heart rates, lost a mean of 1.8% in body weight and averaged 4 hrs of sleep per day suggesting it was also more physically fatiguing than the present one.

The scenario evaluated herein was designed to be as realistic as possible in terms of the frequency and intensity of fire missions, gun movements and other activities performed by the guncrews (US Army Field Artillery School, 1984). Also, in accordance with current doctrine on continuous operations (Field Manual 22-9, 1983), soldiers were encouraged to sleep whenever possible. The crew chiefs were given latitude in rotating individual crewmenbers on the guns so that dedicated sleep could be obtained. To further facilitate sleep, the intensity of the operation was reduced during the early morning hours resulting in 90% of sleep occurring between 2300 and 0700 hrs. Thus sleep deprivation was not as significant a contributer to the overall stress of this study as it was in other scenarios (Murphy et al. 1984; Legg and Patton, 1987). In addition, the relatively little time spent at heart rates exceeding 50% of maximal suggests this scenario to be only "moderate" in terms of its physical intensity. However, this would appear to be in agreement with the observations made by Waldun and Huser (1974) as cited in Rognum et al. (1986) that soldiers during simulated combat situations exceed 50% of their maximal oxygen uptake for only short periods of time.

The significant increases in measures of muscular strength and lifting capacity found during post-testing suggest a possible physiological training effect or a difference in the motivation of soldiers than displayed during the pre-testing period. Because of the relatively low intensity of the scenario and its short duration, it is unlikely that these changes occurred thru a training effect per se as considerably longer periods are usually required to show significant gains in strength (Atha 1981). Part of the increase, however, may be explained by a learning effect due to neuromuscular adaptation which has been shown to account for rapid gains in strength (Sale 1986). In addition, during the post-testing period, there was a general sense of euphoria among the soldiers as a result of successfully completing the trial which was preceeded by significantly greater performance scores on the final day of the scenario. Thus a higher level of motivation (commonly referred to as the end spurt effect) may have accounted for some of the changes seen in muscular strength post-scenario.

The continuous measurement of heart rate appears to provide a suitable means to assess the physical intensity of continuous military operations. However, it must be kept in mind when evaluating such data that heart rate measurement is an indirect estimation of energy expenditure and subject to a large prediction error. Factors such as state of physical training, type of physical activity, emotion, fatigue, etc. can markedly alter the relationship between heart rate and oxygen uptake (Montoye and Taylor 1984). Therefore, no attempt was made in this study to estimate energy expenditure from the heart rate recordings. However, the data do show that high levels of physical activity were attained only infrequently and intermittently and that during the active periods, heart rates averaged below 100 beats/min which equate to an oxygen cost of no greater than 25-30% of maximal aerobic power.

In conclusion, the results of this study show that for individuals obtaining 5 hrs of sleep per day and performing at only moderate exercise intensities, no decrements in physical fitness capacity or evidence of physical fatigue should occur for up to 8 days of continuous operations.

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Table Legends

Table 1. Mean(±SD) data before (pre) and after (post) the 8-day scenario (n=24).

Table 2. Mean (±SD) ratings of physical performance during each day of the scenario (n = number of subjects).

Table 3. Mean (±SD) time spent sleeping and at various intensity levels as determined by heart rate (HR) each day of the scenario (n = number of subjects).

Table 1. Mean (±SD) data before (pre) and after (post) the 8-day scenario (n = 24).

	Pre	Post
Body Composition		
Body weight, kg	75.6 (12.7)	75.9 (12.7)
Body fat, %	16.3 (3.7)	15.6 (3.6)*
Fat free mass, kg	63.0 (9.1)	63.8 (8.8)*
Upper body anaerobic power		
Peak power, W/kg	7.79 (0.72)	7.90 (0.72)
Mean power, W/kg	6.00 (0.54)	6.20 (0.56)
Power decrease, %	44.5 (9.6)	43.0 (8.0)
Muscular strength		
Elbow flexors 30°/s, NM	55.3 (10.0)	62.1 (12.2)*
Elbow flexors 180°/s, NM	41.5 (8.5)	48.7 (11.7)*
Knee extensors 30°/s, NM	212 (58)	249 (57)*
Knee extensors 180°/s, NM	147 (35)	167 (37)*
Handgrip, kg	62.7 (7.8)	66.9 (10.5)*
Incremental dynamic lift, kg	73.4 (15.3)	83.7 (16.2)*

* $p<.05$

Table 2. Mean (±SD) ratings of physical performance each day of the scenario (n = number of subjects).

	Day 1	2	3	4	5	6	7	8	Mean
Score	6.8(1.6)*	6.3(1.6)	6.2(1.4)	6.4(1.4)	6.3(1.1)	6.0(0.8)	5.7(1.0)	6.8(0.8)*	6.3(1.2)
n	23	23	2 2	22	22	20	20	22	

* p<.05, compared to other days (Day 1 and Day 8 not significantly different).

Table 3. Mean (± SD) time spent sleeping and at various intensity levels as determined by heart rate (HR) each day of the scenario, n = number of subjects).

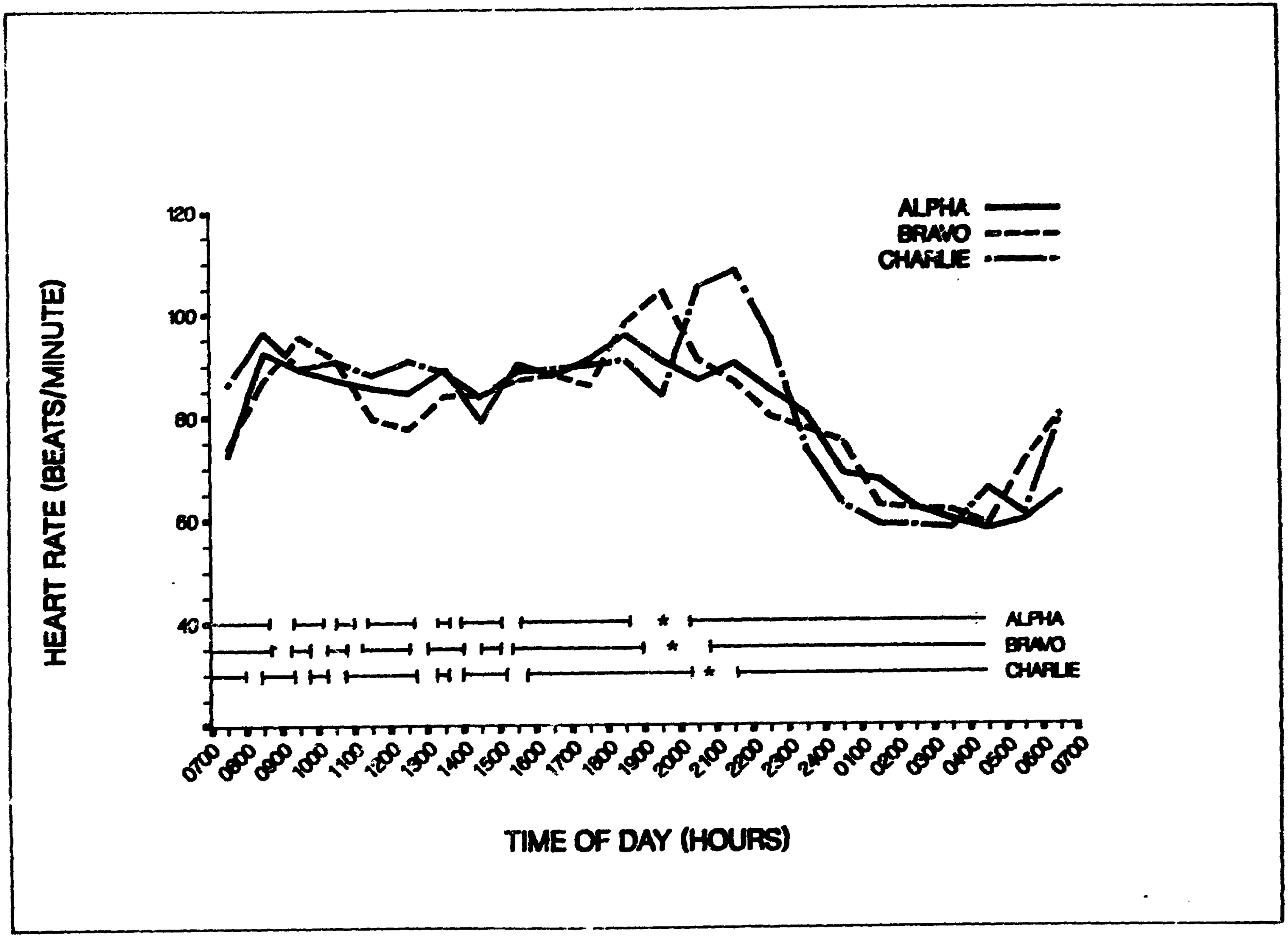
	Day								
	1	2	3	4	5	6	7	8	Mean
Sleep, hr	5.6 ±1.4	5.5 ±1.6	4.7 ±1.0	5.3 ±1.0	5.3 ±1.0	4.8 ±1.5	5.5 ±1.2	5.3 ±1.2	5.3 ±1.3
Baseline HR, hr	5.2 ±2.3	6.5 ±2.6	6.4 ±3.1	6.7 ±2.8	5.2 ±2.0	5.2 ±2.5	3.4 ±2.5	5.6 ±2.9	5.5 ±2.8
HR 50%, min*	14.9 ±15.1	14.6 ±15.7	18.6 ±17.1	26.4 ±18.7	28.8 ±30.4	29.2 ±24.0	23.6 ±21.3	19.5 ±23.0	22.0 ±20.7
HR 75%, min**	1.4 ±2.5	0.9 ±2.2	2.3 ±4.3	3.6 ±4.4	3.5 ±5.0	6.1 ±8.1	2.1 ±3.6	3.6 ±6.8	2.9 ±4.6
n	12	15	20	18	13	13	13	11	

* HR 50% of maximal exercise HR, mean 134±5 bpm.

** HR 75% of maximal exercise HR, mean 163±6 bpm.

Figure Legends

Figure 1. Mean hourly heart rates for each guncrew during Day 4 of the scenario. Depicted at bottom are periods of occupation of (|—|) and displacement from (⊣ ⊢) gun positions. The period of ammunition resupply is designated as (*).



ALPHA
BRAVO
CHARLIE
HEART RATE (BEATS/MINUTE)
120
100
80
60
40
ALPHA
BRAVO
CHARLIE
0700 0800 0900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 0100 0200 0300 0400 0500 0600 0700
TIME OF DAY (HOURS)